UNITED STATES DEPARTMENT OF AGRICULTURE

North American Animal Health Committee Conference

July 9-11, 2002
Fort Collins, CO

Welcome

It is my pleasure to invite you to attend a disease-spread modeling workshop. The workshop is sponsored by the North America Animal Health Committee (NAAHC), Emergency Management Working Group and is hosted by the USDA's Centers for Epidemiology and Animal Health. The workshop will be held July 9-11, 2002, in Fort Collins, Colorado.

The Emergency Management Working Group, with membership delegations from Canada, Mexico and the USA, is responsible for a coordinated response to incidents of foot and mouth disease (FMD) in North America. Management of the North American FMD vaccine bank is one of NAAHC's fundamental responsibilities.

The primary purpose of this workshop is to identify appropriate management decision support tools for planning FMD outbreak mitigation actions, including vaccination. Several disease spread models will be discussed. These models, with integrated economic components, simulate the progression of an outbreak under a variety of conditions, and estimate the economic benefits and costs of the outbreak and the impacts of mitigation options. Explicit data requirements and inherent assumptions of the models also will be discussed. A secondary purpose of the workshop is to facilitate the interchange of disease spread and economic modeling methods and techniques among analysts actively engaged in these activities.

We look forward to your participation in this very important workshop.

Thomas E. Walton, Director

Special points of interest:

- Conference Agenda
- Biographies
- Summary of Model Presentations

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Centers for Epidemiology & Animal Health
An OIE Collaborating Center

North American Animal Health Committee (NAAHC)
Emergency Management Working Group
Disease Spread Modeling Workshop
Agenda
July 9-11, 2002

Day 1

8:00-8:10	Meeting Objectives
8:10-9:10	Role of Modeling in Decision-Making
9:10-9:25	*Break*
9:25-10:55	Australia Model by Dr. Graeme Garner, Australia
10:55-11:00	*Break*
11:00-12:30	Netherlands Model by Drs. Franka Tomassen and Monique Mourits
12:30-2:00	*Lunch*
2:00-3:30	UC Davis Model by Dr. Tim Carpenter
3:30-3:45	*Break*
3:45-5:00	Economic Modeling by Dr. Ken Forsythe
7:00 pm	Dinner hosted by Dr. John Belfrage and Dr. Paula Cowen at their home

Day 2

8:00-8:30	Summary of Day 1
8:30-8:45	*Break*
8:45-10:45	USDA FMD Model by Dr. Mark Schoenbaum
10:45-10:50	*Break*
10:50-12:00	USDA TB Model by Dr. Craig Chioino
12:00-1:30	*Lunch*
1:30-5:00	Discussion of pros & cons of each model

Day 3

8:00-8:30	Summary of Day 2
8:30-8:45	*Break*
8:45-10:45	Discussion *Required Attributes & Outputs *Data Sources
10:45-11:00	*Break*
11:00-12:00	Discussion Continued *Specific Scenarios
12:00-1:30	*Lunch*
1:30-2:30	Discussion Continued *Economics
2:30-2:45	*Break*
2:30-5:00	Technical Discussion

Dr. Graeme Garner, Australia

Dr Graeme Garner is a veterinary science graduate of the University of Sydney. Following several years in veterinary practice he spent 5 years in biomedical research (renal and cardiovascular physiology) in the early 1980s. During this time he completed a PhD degree at the University of Sydney.

He joined the Bureau of Rural Resources in the Commonwealth Department of Primary Industry (now the Department of Agriculture, Fisheries and Forestry) as a Veterinary Officer in late 1986. In March 1990, he was promoted to Principal Veterinary Officer running the Epidemiology sub-section of the Animal Health Branch. The Branch's role was to provide scientific advice and technical support to the Department on animal health and quarantine issues concerned with improvement of the health status of Australia's farm animals and promotion of the safer international movement of agricultural products.

In 1991 he was appointed as a Senior Research Scientist in the Animal Health Branch. His main responsibilities at this time included disease surveillance and reporting (including Australia's international animal health reporting obligations), epidemiological studies of exotic and endemic animal diseases (particularly foot-and-mouth disease and other exotic disease threats) and management of Australia's Wildlife and Exotic Disease Preparedness program (WEDPP). In June 1995 he was promoted to Principal Research Scientist (Epidemiology)

Following a Departmental restructure in 1998, the Animal Health Branch was moved out of the Bureau Rural Science and into the newly created National Office of Animal and Plant Health. In 2000, the National Office of Animal and Plant Health was reorganized and along with a number of other scientists, Dr Garner was transferred to the newly formed Animal Health Science Unit in the Office of the Chief Veterinary Officer.

Modelling foot-and-mouth disease in Australia

Graeme Garner
Animal Health Science Unit
Office of the Chief Veterinary Officer
Department of Agriculture, Fisheries and Forestry - Australia

Background

There are several different approaches to modelling infectious diseases in animal populations. One common approach is to divide a population into compartments and model movement between compartments by a series of differential equations. These are continuous time models and many people will be familiar with these models from the work of Anderson and May and colleagues in the UK. It is fairly widely accepted that these models tend to be generalised and tend to sacrifice to a greater or lesser extent biological reality for mathematical tractability. As such, they are more suited to studying infectious processes rather than being predictive. Because they are reasonably quick to develop they are reasonably commonly used and there is now quite an extensive literature, covering a wide range of applications of this type of model.

An alternative approach to mathematical modelling is simulation modelling. In this form of modelling, the population is made up of a series of individuals, representations of biological processes are constructed and the outcome of events is determined by sampling from probability distributions using 'Monte Carlo' methods. Time is usually handled in discrete steps e.g. day, week, month etc. Simulation models tend to be more biologically 'real' but are more complicated than simpler mathematical models and take considerably longer to develop.

Australian model

The model used in Australia is a state-transition simulation model developed from a Markov chain, modified to include stochastic elements. The background to this model can be traced to the work of Miller (1979) and James and Rossiter (1989), although it has been considerably expanded in terms of scope and application from these early models.

Because in Australia most exotic disease management activities operate at the herd level (e.g. quarantine, stamping out vaccination), the flock or herd is the unit of concern and the model will simulate herd-to-herd spread of disease. (N.B. The concepts apply equally to individual animals and the same type of model with appropriate parameterisation can be used to simulate animal-to-animal spread of disease.) The model is designed to operate in a regional setting, using appropriate values for various parameters. A region is defined as an area that is reasonably homogenous in terms of climate and production systems. As the model includes stochastic elements, it can give different results each time it is run, even with the same starting parameters. The model is run multiple times to generate a meaningful distribution of likely outcomes. To simulate a large multi-focal outbreak, separate versions of the model can be set up to run in each affected region and the outputs combined to generate the overall epidemic.

Applications

The model was initially developed as a generic model that could be adapted to study a range of (predominantly exotic) animal diseases in order to assess the potential size and impact of disease outbreaks and to evaluate various control strategies. Although the model has been used to study disease like sheep pox, hog cholera, PRRS, Nipah virus, most of the development work has been undertaken in relation to FMD.

The model began as a relatively simple herd-based model that operated using a weekly time step, and relatively static parameter values. It has been subsequently been extensively modified to take into account different herd types in the population, variable ranges for parameters such as latent, infectious and immune periods, different types of control activities, and resource constraints, depending on application. The more recent versions also operate at a finer temporal scale (daily time step).

Model description

In a state-transition model, there are four possible basic disease-related 'states' that herds in the population could be in:

1. Susceptible - to the disease
2. Latent – infected but not yet infectious to other herds
3. Infectious – infected with the disease and capable of spreading disease
4. Immune - by virtue of recovery from the disease or by immunisation
5. Dead - i.e. slaughtered/destocked

These states are mutually exclusive. During any time period, depending on various factors, a herd has a probability of remaining in that state or moving to another state (a 'transition'). For example, if a susceptible herd comes in contact with an infected herd there is a probability that it will become infected. This will involve a transition *susceptible to latent*. Similarly after a time interval (determined by the latent period), a latent herd will become an infectious herd — transition from *latent to infectious*. An infectious herd if it is recognised will be removed under a slaughter policy, and in the model this is simulated buy an *infectious to dead* transition. If it is

not recognised it will progress, after a time interval (determined by the infectious period), to become an immune herd. If a dangerous contact (DC) slaughter policy is used then herds exposed to the disease but not yet recognised clinically will be removed — a dangerous contact could in fact be latent, affected or immune (i.e. *latent to dead*, *infectious to dead* or *immune to dead* transitions. However, because tracing is unlikely to be 100% effective DC slaughter will result in some innocent (susceptible) herds being removed — *susceptible to dead* transitions. As part of sero-surveillance, immune herds may be identified and removed — *immune to dead* transition. If vaccination is used, it is simulated by a *susceptible to immune* transition

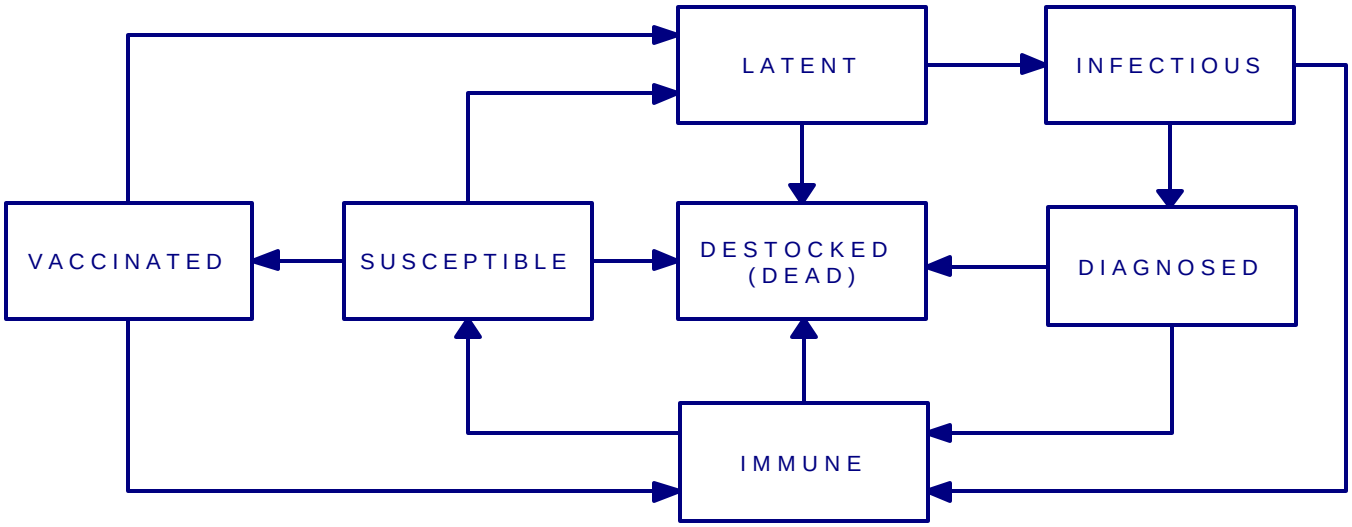
These concepts form the basis of a 'state-transition' model. The logic is relatively straightforward. The complexity comes in with how and when transitions occur. Movements of animals between states can be thought of as being controlled by a series of *rules*. These rules can be modified to take into account various factors such as type of control strategy that is used, availability of resources, etc. A distinct advantage of simulation models is their flexibility in this regard. Further 'states' can be added as the model becomes more sophisticated. For example, where all resources to stamp out infected herds may have been used up, an intermediate state to allow for herds that have been diagnosed but not yet removed can be included in the model.

Most of the transition rules depend on values ascribed to various disease and control 'parameters'. Some of the basic disease and control parameters and the way they are managed in the model are briefly described below.

Disease Parameters

FMD Model

States and Transitions



Latent Period

The period from when a herd first becomes infected until it becomes 'infectious' i.e. capable of infecting other herds. Minimum and maximum possible values are defined and the model randomly selects duration from a rectangular distribution.

Infectious Period

The period during which an infected herd can spread infection to other herds (NB not the duration of infectivity in individual animals). The infectious period depends on the type and size of the herd, husbandry practices and whether the disease is allowed to run its course or controls (e.g. slaughter) are applied. The user specifies triangular probability distribution for duration of infectious period in the model by herd type, to reflect different herd sizes and management systems in the study population. The model randomly selects a value from the probability distribution

Immune Period

The period from the end of the infectious period until the herd is again susceptible. In the model a user-defined distribution for duration of immunity is specified. For a herd, this relies on the concept of herd immunity. Immunity in cattle following infection with FMD lasts at least 2–3 years after homologous virus. However, in a herd the number of immune animals will fall as a result of turn-off, deaths etc. and the number of susceptible animals would start to accumulate through births and purchases. Pig herds, with a much more rapid turnover in stock, would be expected to have a much shorter immune period. Because Australia's approach will be to remove all infected and seropositive herds, a simple approach to immune period has been adopted in the model. A user-defined cumulative probability table is used to randomly set the immune period. Depending on the relative mix of herd types in a region the distribution may need to be adjusted.

Effective contact rate (also known as Dissemination rate)

The probability of a susceptible herd becoming infected is a function of the number of infected herds in the population and the disease *dissemination rate (DR)*. DR is defined as the expected number of herds coming into contact with each infective herd per unit of time, contact being sufficiently close that disease transmission could occur. The status of the contacted herds is not considered. For the model it is specified as an average weekly value. Contact is used in its broadest sense and relates to *all* routes by which the disease under study could be spread from one herd to another, including movement of people, animals, materials, windborne spread, etc.

DR is the most difficult parameter of any model as it depends on characteristics of the disease agent, the host population and the environment, including management practices and time of year. In the absence of any definitive data, it has to be estimated from values observed elsewhere for the disease and extrapolated to local conditions. DR can be estimated retrospectively from actual outbreaks overseas, or it can be estimated from studies of the extent and type of 'contacts' between farms, or a combination of these. The other factor that needs to be considered is that DR is likely to vary with time of year e.g. seasonal conditions will affect virus survival outside the host, while husbandry and management factors at different times of the year will affect the degree of mixing of animals and herds.

Control Parameters

Quarantine and movement restrictions

Quarantine, movement restrictions, saleyard and market closures will slow the rate of disease spread and they can be represented in the model by a reduction in DR, although this relationship is difficult to quantify. The approach used in the model is to proportionally reduce DR over a period of about 6 weeks, based on empirical data from overseas outbreaks (UK 1967–68 and UK 2001).

Stamping-out

Slaughtering infected herds will decrease the number of sources of infection. The model simulates a stamp-

ing-out policy by an *infected to dead* transition. Probabilities that infected herds are recognised and removed within different time periods after becoming infected are specified. The maximum number of herds able to be stamped out per week can be set, to allow for resource constraints. This number is assumed to increase with time as authorities assemble more resources and become more efficient.

In the more detailed daily version of the model, stamping out has been split into two separate processes — recognition (probability that an infected herd will be found, with time to detection) and removal (probability that an identified herd will be removed in a given time period, which depends on resource availability).

Dangerous contact slaughter

Dangerous contact (DC) herds are herds that although not showing disease symptoms are considered to be 'at high to very high risk' of developing the disease either because of proximity or potential contact with infected herds based on tracings. DC slaughter will remove herds 'exposed' to the disease (*latent, affected* or *immune*) and thus reduce the number of infected herds in subsequent weeks. As tracing procedures are unlikely to be 100% effective, not all herds removed by DC slaughter will have the disease, and a proportion of disease-free herds are also likely to be removed. When DC slaughter is used, it is necessary to estimate the expected average number of DCs per infected herd. This is likely to depend on regional factors, herd type management system, time of year, etc. Like DR, the number of DCs can be expected to fall with time once control measures like movement restrictions take effect, and is allowed for in the model. It is also necessary to estimate what proportion of DC herds are actually likely to have been exposed to the disease — this will depend on the type and location of the outbreak and especially on the tracing skills of disease control authorities. This value is used to partition DCs as either *susceptible* or exposed (*latent, affected or immune*) herds. DC herds will be removed, depending on resource availability. If resources are limited, a backlog of DC herds waiting slaughter can build up.

Vaccination

In the model, vaccination is simulated by a *susceptible to immune* transition. In the daily version of the model there is an intermediate state (vaccinated but not yet immune) to allow for the fact that there is a lag between when vaccine is administered and when animals will be immune. During this period, herds can still become infected, even though they have been vaccinated.

Ring vaccination would involve vaccination of all herds in a ring of given width around each infected area thus creating a vaccination *buffer*. As the model is non-spatial it is necessary for the user to set the number of separate foci of infection. The operator specifies when vaccination begins (either by time into the control program or by epidemic size), the number of separate infected areas, the width of the vaccination ring required and the average number of herds able to be vaccinated per week. As with stamping out, it is assumed that the number of herds able to be vaccinated per week increases over time (as more resources become available). As a first approximation, it is assumed that vaccination zones will be circular. Using average herd densities for the region under study, the sizes of vaccination zones and numbers of stock they contain can be determined. The spatial nature of a ring vaccination strategy, which produces a local reduction in number of susceptible herds is allowed for, by reducing DR. The model assumes that reduction in rate of disease spread during vaccination will be proportional (but not linear) to the number of susceptible animals remaining in the vaccination zone(s) up to a maximum of 90%. That is even when all herds within the target areas are vaccinated there is still a chance that disease could spread (to allow for possible vaccination failure, spread outside of the zone, etc). It is obvious that, all other things being equal, the smaller the size of the vaccination operation, the more quickly the disease will be eradicated and it is necessary to assume that a common sense approach is adopted and that the width of the zone would be adequate to contain the disease.

Data needed to set up model

General background on region under study

- ? Nature and type of livestock production,
- ? Management/husbandry systems
- ? Selling and buying patterns

Demographic information

- ? Size of region
- ? Number of herds/flocks at risk (beef, dairy, sheep, pigs, goats, smallholders, etc)
- ? Number of animals by species

*Assumptions that have to be made***:**

- ? Rate of spread that will apply for the disease under study for each region: - expressed as the initial DR.
- ? Duration and distribution of latent, infectious and immune periods for the disease by different herd types.
- ? Delay from when the disease is introduced until it is recognised and control measures implemented in the region.
- ? Efficacy of control measures i.e. how good will authorities be in implementing controls, as measured by:
  - reduction in disease spread due to quarantine and movement restrictions;
  - what proportion and how quickly are infected herds likely to be identified, by type.
- ? In the region under study, what is an upper limit on the number of herds able to be stamped out per week? How might this increase over time?
- ? If dangerous contact slaughter is used, what is the expected average number of DCs per infected herd for the region based on proximity and tracings? What proportion of truly 'exposed' herds will be removed through tracing (i.e. how good will the investigations/tracing teams be?)?
- ? In the region under study what is an upper limit on the number of herds able to be vaccinated per week. What proportion of the resources should/would be allocated to vaccination.

Model operation

The model is written in Turbopascal (currently being rewritten in Visual Basic). To run the model, the user specifies:

- ? The number of infected herds/flocks at the start
- ? The DR that applies at the start of the outbreak (this will fall once control measures are implemented)
- ? The delay from introduction until the disease is recognised
- ? The type of controls applied (i.e. stamping-out of infected herds only, stamping-out of infected and dangerous contact herds, or stamping-out plus ring vaccination)
- ? If dangerous contact slaughter is used it will be necessary to specify the average number of dangerous contacts expected per infected herd and the probability (proportion) of DC herds that are actually likely to be incubating the disease. NB the number of DCs falls with time.
- ? If vaccination is used, it is necessary to specify when vaccination begins, the number of separate infected areas, the width of the vaccination ring to be used
- ? The number of simulation runs to do

The program reads in the regional information (size of region, number of herds by type), distributions for latent, infectious and immune periods, and probability distribution of detecting and removing infected herds by time from a data file.

Resource constraints, in terms of the numbers of herds able to be stamped out or vaccinated by week, are included in the program.

The model will run the simulations and save the results in a text file for subsequent analysis. The main outputs are:

- Epidemic curves
- Duration of the epidemic (how long the disease lasts)
- Number of herds/flocks affected by the disease
- Number of herds/flocks removed to achieve eradication.
- Number of herds/flocks vaccinated

From this information actual numbers of livestock involved can be estimated using average herd and flock sizes for the study region.

The model also keeps track of timing and occurrence of a wide range of events and herd statuses associated with the outbreak e.g. when new cases occur, when herds are diagnosed, stamped out, vaccinated etc.

Further information is available in various publications (see separate list).

Future developments

1. The model is being re-written in a more modern programming language (Visual Basic).

2. Further consideration of resourcing issues, especially impact on surveillance activity and probability of finding/diagnosing infected herds.

3. Exploring spatial modelling. The model could be readily adapted to run in a true spatial setting using real farm data. However, this approach will require good spatial data on farms and information on livestock movement patterns (both at the regional and farms levels). A good understanding of the relative importance of different mechanisms of spread in different regions and at different times of the year is essential.

Dr. Franka Tomassen

Education
MSc Agricultural Economics, Wageningen Agricultural University, 1996

Current position
PhD student at the Farm Management Group, Department of Social Sciences, Wageningen University.

Research
The main goal of the PhD-project is to define effective control strategies taking into account the specific characteristics of the densely populated livestock area in the Netherlands. To make sound decisions from a disease point of view as well as from an economic point of view, therefore, an integrated modeling approach is required that simulates the effects of different conditions and scenarios considering: (1) the spread of the disease, (2) the direct cost of control measures, (3) the indirect effects due to trade restrictions, and (4) social-psychological and ethical aspects of control of FMD.
A decision tree is developed to optimize decisions on control measures after the declaration of foot-and-mouth disease.

Publications
F.H.M. Tomassen, A. de Koeijer, A. Dekker, A. Bouma and R.B.M. Huirne. A decision tree to optimise control measures during the early stage of a foot and mouth disease epidemic. Accepted for publication in Prev. Vet. Med.

Horst, H.S., De Vos, C.J., Tomassen, F.H.M. and Stelwagen, J. (1999) The economic evaluation of control and eradication of epidemic livestock diseases. Revue Scientifique et Technique de Office International des Épizooties, 18(2): 367-379.

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Economic evaluations of the FMD epizootic for agriculture and trade

Franka Tomassen, Monique Mourits & Ruud Huirne

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Successful economic eradication of an FMD epidemic mainly depends on the selected control strategy and on the time interval between diagnosis and implementation of the control strategy. Selecting an inadequate strategy may cause large additional economic losses. Delayed implementation of control measures may cause extensive spread of the disease. This means that it is very important for animal health authorities to

make the right decision immediately after the first diagnosis. Usually there is no time to gather additional data to support decision-making. Therefore, it is absolutely essential to have an overall analytic structure for these kinds of situations beforehand.

We developed a tool, that can serve as an analytical framework for economic analysis, to support decision-making on control strategies during the early stage of an epidemic. This tool comprises a decision tree using all information available in the first three days after the declaration of an outbreak. The information concerns mainly the livestock and herd density in the outbreak region, the possibility of airborne spread and an estimation of the period between first infection and first detection.

The objective of the decision tree is to calculate the economically optimal control strategy for each situation. Economically optimal means that direct costs and export losses are minimised. A calculation has been made for the Netherlands.

The starting point of the tree is an epidemiological model. This model uses contact patterns of different farm types to simulate the spread of the disease. The effect of four control strategies on FMD dynamics have been modelled. Based on the current EU legislation and analyses of recent epidemics, the following control strategies are considered in this study:

1. stamping-out of infected herds (85/511/EEC) and culling of high-risk contact herds (SO);
2. SO extended with ring culling of all susceptible animals within a radius of 1 km of an infected herd (RC1);
3. SO extended with ring vaccination of all susceptible animals within a radius of 1 km of an infected herd (VC1);
4. SO extended with ring vaccination of all susceptible animals within a radius of 3 km (VC3).

All four strategies include movement control. The last three strategies also took into account the possibility of airborne spread outside implemented rings. Susceptible animals outside a ring but downwind of a virus plume were culled or vaccinated respectively. Vaccinated animals were culled as quickly as possible to keep the necessary period for regaining the status of FMD-free country without vaccination as short as possible. Here, culling and destruction capacities were the restricting factors.

An economic model converted outbreak and control effects of farming and processing operations into estimates of direct costs and consequential export and trade losses. The extent of the consequential export and trade losses depends on the duration and size of the epidemic and the reactions of importing countries during and after the epidemic. These reactions are distracted from international trade restrictions during recent epidemics.

The calculations show that animal density within the outbreak region is an important determinant in deciding on the optimal control strategy. There is a considerable regional variation in the size of impacts. The results also indicate that the export losses are much higher than the direct costs.

Ring vaccination is the economically optimal strategy for densely populated livestock areas because this strategy reduces the number of infected herds and the duration of the epidemic compared to the other strategies. Ring culling is the economically optimal strategy for sparsely populated livestock areas. For livestock areas that are neither very densely populated nor very sparsely populated, the optimal strategy depends on the period between first infection and first detection and the presence of airborne spread.

The duration of an epidemic is one of the most important parameters, which determined the economic impact of an epidemic. In densely populated livestock areas the culling and rendering capacity is the limiting

factor, causing delays in culling and extension of the epidemic. Therefore, ring vaccination is the optimal strategy in these areas because it reduces the number of infected farms and likewise the duration of the epidemic. These results can be used as yardsticks for deciding on control measures during possible FMD epidemics in the future.

Statements for discussion

- Power of ring vaccination in densely populated livestock areas is usually underestimated
- Huge impact of trade restrictions on economic losses, and therefore on economic optimal strategies, is not always recognised.
- Importance of regionalisation principle for reduction of trade losses.

Dr. Monique Mourits

Education:

MSc Animal Science, Wageningen Agricultural University, 1990 - 1994.
PhD Farm Management, Wageningen Agricultural University, 1995 - 2000

Current position:

Researcher / lecturer at the Farm Management Group, Wageningen University

Research:

PhD - Project (June 1995 - Jan. 2000):
Economic modeling to optimize dairy heifer management decisions.
In this research project a dynamic programming model was developed to optimize the rearing strategies of dairy heifers, using the Hierarchic Markov Process (HMP) technique.

Current research (start July 1999):

Technical and economic simulation of foot and mouth disease control strategies .
Decisions on what strategy is best to apply in case of a FMD-outbreak are highly subject to uncertain conditions, especially with respect to the risk of outbreaks and foreign trade restrictions. A modeling approach is required that integrates (a) the spread of the disease, (b) the effects of control strategies on disease spread and (c) the economic consequences such as direct costs of eradication and indirect costs due to export bans. In this project, the spatial and stochastic simulation model, InterFMD, will be further developed and modified to explore the epidemiological and economic effects of a FMD-outbreak in The Netherlands.

Teaching:

Courses:

- Analysis of farm production systems
- Animal Health Economics
- Information and Decision Making in Agriculture
- Agricultural Business Economics

Recent publications:

Tomassen, F.H.M., Koeijer, A. de, Mourits, M.C.M., Dekker, A., Bouma, A., Huirne, R.B.M. 2002. A decision tree to optimise control measures during the early stage of a foot-and-mouth disease epidemic. Accepted by *Preventive Veterinary Medecine*.

Mangen, M.J.J., Burrell, A.M., Mourits, M.C.M., 2002. Welfare effects of controlling the 97/98 Classical Swine Fever epidemic in the Netherlands. Submitted to *Agricultural Systems.*

Mourits, M.C.M., Nielen, M. and Léon, C.D., 2002. Effect of control measures on the course of simulated foot and mouth disease epidemics that started in different farm types in various Dutch areas. In: Proc. Of the Society for Veterinary Epidemiology and Preventive Medicine (SVEPM) 2-5 April, Cambridge, England, pp. 190-200.

Mangen, M.J.J., Jalvingh, A.W., Nielen, M., Mourits, M.C.M, Klinkenberg, D., Dijkhuizen, A.A., 2001. Spatial and stochastic simulation to compare two emergency-vaccination strategies with a marker vaccine in the 1997/98 Dutch Classical Swine Fever epidemic. *Preventive Veterinary Medicine* 48 (3), 177-200.

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General framework of the simulation model InterFMD

Monique Mourits & Mirjam Nielen

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In our research, the simulation model, InterFMD, is used to simulate the spread and control of a FMD epidemic on a day-by-day basis. The conceptual model of InterFMD, InterSpread, was developed by Sanson (1993) as part of EPIMAN, a decision support system for the control of FMD outbreaks. Jalvingh et al. (1998, 1999) developed and modified InterSpread to match Dutch conditions in general. In this general model, spread of FMD was simulated based on the characteristics of an 'average species'. In the modified InterFMD model (Mourits et al., 2002) species-specific contact structures were included to define species-specific spread mechanisms.

Within the general framework of InterSpread/InterFMD, the spatial, stochastic and dynamic simulation of the spread and control of FMD starts with an initialisation phase, in which the farm specific data (e.g. geographic location, number of animals) are loaded into the model and the spread and control mechanisms

are assigned their parametric value. All spread and control mechanisms act spatially by using the geographic location of farms and contain variation and uncertainty (mostly reflected by empirical probability functions). As a result of this Monte Carlo simulation, several replications, each representing a possible course of an epidemic, are necessary to get insight into the possible range of outcomes.

At the start of each replication, the primary infected farm is initialised. The disease spread from the infected farm is simulated through three different spread mechanisms: 1) contacts by animals (= high risk), vehicles (= medium risk) or professional persons (= low risk), 2) local/neighbourhood spread, and 3) airborne spread. When the disease spread results in the infection of another farm, this farm is assigned relevant dates (e.g. moment of infectiousness) and will become one of the list of infected farms. In the situation where detection of an infected farm takes place, control measures are initialised. Control measures apply to the infected farm (e.g. stamping out), all farms within a certain radius around the infected farm (e.g. pre-emptive slaughter, movement control, suppressive vaccination) and contact farms that have been traced (e.g. pre-emptive slaughter, movement control).

The output of InterSpread/InterFMD consists of descriptive epidemiological characteristics of the simulated epidemic, such as the number of infected farms, the number of pre-emptively slaughtered farms, the number of farms in control zones and the duration of the epidemic. These simulated epidemiological results can be used to evaluate the economic consequences of the various control strategies. In general, the economic loss of a FMD epidemic is strongly correlated with the duration of the epidemic and, for exporting countries, the duration of the imposed export bans (Tomassen et al., 2002).

The general framework of the InterFMD model is also suitable for the simulation of other infectious diseases. Similar models have been developed to simulate CSF epidemics (Mangen et al., 2001) and bovine herpesvirus type I epidemics (Vonk Noordegraaf et al., 2000). Currently, efforts are made to develop a generic disease simulation model, named InterSpreadPlus. This generic model will provide the user with a set of tools that can be used to simulate the actual events of a disease outbreak. The tools can be configured in a variety of ways to allow the user to simulate the behavior and dynamics of any particular disease.

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CAREER/EMPLOYMENT

1976-78	RESEARCH ASSOCIATE/LECTURER, UNIVERSITY OF CALIFORNIA, DAVIS
1976-78	STAFF EPIDEMIOLOGIST-ECONOMIST, INTER-AMERICAN DEVELOPMENT BANK, WASHINGTON, D.C.
1979-80	LECTURER, UNIVERSITY OF CALIFORNIA, DAVIS
1980-87	ASSISTANT PROFESSOR, UNIVERSITY OF CALIFORNIA, DAVIS
1987-91	ASSOCIATE PROFESSOR, UNIVERSITY OF CALIFORNIA, DAVIS
1991	PROFESSOR, UNIVERSITY OF CALIFORNIA, DAVIS

SPECIALIZATION

MAIN FIELD: EPIDEMIOLOGY

OTHER FIELDS: SIMULATION MODELING, ANIMAL HEALTH ECONOMICS, RISK ANALYSIS, SPATIAL STATISTICS

CURRENT RESEARCH INTEREST: TEMPORAL AND SPATIAL CLUSTER STATISTICS, RISK ANALYSIS OF DISEASE IMPORTATION AND ERADICATION

Consulting

1976-77	Evaluation of the economics of anaplasmosis control in California - California Department of Food and Agriculture
1977-78	Evaluation of alternative brucellosis eradication programs and economic aspects of rural veterinary service: a benefit-cost analysis - University of Florida.
1978-80	Epidemiologic and economic evaluation of foot and mouth disease in Latin America - Inter-American Development Bank, Wash., D.C.
1980-83	Major bottlenecks of the Egyptian poultry industry - USAID.
1980-81	Economic impact of foot-and-mouth disease in Brazilian cattle - Pan American Health Organization, Brazilian Ministry of Agriculture and Inter-American Development Bank.
1985	Measure the economic impact of poultry diseases in the US - Food and Agriculture Organization (FAO)
1985-86	Epidemiologic\economic ex-post evaluation of the foot-and-disease control program in Ecuador: a benefit-cost analysis - Inter-American Development Bank.
1999-00	Methodologies for Evaluating Animal Health Programs in Mexico - Food and Agriculture Organization (FAO), SAGAR, Alianza para el Campo

Invited lecturer or short courses presented

1984	Veterinary economics - 1 week course taught in Skara, Sweden to 42 veterinarians - FAO.
1986	Visiting professor in animal health economic, presented a 1 week series of lectures to the University, Veterinary College and Department of Veterinary Microbiology and Immunology at the University of Guelph, Ontario, Canada.
1988	Veterinary epidemiology and economics - 2 week course taught in Tune, Denmark to 43 veterinarians - FAO.
1991	Veterinary epidemiology and economics - 2 week course taught in Biri, Norway to 42 veterinarians - FAO.
1995	Veterinary epidemiology and economics - 2 week course taught in Tune, Denmark to 44 veterinarians - FAO.
1998	Veterinary epidemiology and economics - 2 week course taught in Suitia, Finland to 44 veterinarians - FAO.

Factors potentially influencing a foot-and-mouth disease (FMD) epidemic in the U.S.

The presentation provides an overview of some of our work modeling foot-and-mouth disease (FMD) epidemics, using a spatial-temporal stochastic model with ~ 40 parameters, 3 modes of transmission, and 12 herd types. An epidemic was simulated for conditions assumed to exist currently for diagnosis and control, as mandated by the USDA, which include slaughter of infected herds and implementation of quarantine and restrictions on livestock movement within specified 'surveillance zones' and 'infection regions' implemented as soon as FMD was diagnosed. The mean number of herds infected

for simulations of an epidemic controlled by the mandatory procedures, referred to as the baseline epidemic, were compared with those for simulations considering various other diagnostic and control scenarios. Results suggest that vaccination could be a possible control strategy, if the appropriate vaccine serotype was efficacious and very readily available. Preemptive ring slaughter was estimated to be more costly and less effective than preemptive slaughter only of highest risk herds surrounding an infected herd. Of particular importance were results suggesting that effective control of FMD will depend on 1) a much earlier diagnosis of both index and secondary cases than is possible now, 2) effective biosecurity systems being in place by herd owners well before the epidemic, 3) effectiveness of mandatory restrictions used to prevent animal, personnel, and vehicle movement among herds at the time of an epidemic, and 4) the ability to implement the slaughter of infected herds immediately after FMD has been diagnosed.

Dr. Kenneth W. Forsythe Jr.

Kenneth W. Forsythe Jr. is an Agricultural Economist working for the Centers for Epidemiology and Animal Health (CEAH) in Fort Collins, Colorado. CEAH is a unit within the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Veterinary Services.

Dr. Forsythe's work at CEAH had been primarily in the area of animal health risk analysis and evaluating the benefits and costs of livestock disease prevention, control, or eradication policies and programs; particularly those related to international trade and foreign animal diseases. Dr. Forsythe has worked for CEAH since 1993, when he transferred from the U.S. Department of Agriculture, Economic Research Service.

Dr. Forsythe worked for the Economic Research Service from 1991 to 1993 in the Agriculture and Trade Analysis Division. Much of this work focused on the North American Free Trade Agreement and the General Agreement on Tariffs and Trade; particularly the sanitary and phytosanitary provisions of these agreements.

Dr. Forsythe received his Ph.D. in Agricultural Economics from the University of Missouri-Columbia in 1991 where he specialized in sanitary and phytosanitary issues in international agricultural trade. He received M.S. and B.S. degrees in Agricultural Economics from the University of Nebraska-Lincoln.

Dr. Mark Schoenbaum

Currently an analytical epidemiologist at the Centers of Epidemiology and Animal Health in Fort Collins, CO.

Practiced as a veterinarian in livestock practices in IA and MN after graduating from Iowa State University. Returned to graduate school in microbiology and epidemiology at Iowa State and earned MS and PhD degrees.

He then worked as a Regional Epidemiologist for Veterinary Services for 10 years with emphasis on the TB and pseudorabies programs.

For the last 3 years at CEAH, Dr. Schoenbaum has been working on different strategies for animal health surveillance including more comprehensive and integrated approaches. He has also been involved in modeling the potential spread of foreign animal diseases.

Dr. Craig Chioino

Craig Chioino is presently a Risk Analyst for Policy Program Development, Risk Analysis Systems, USDA-APHIS. He has occupied this position since 1995. He received a Doctorate in Veterinary Medicine from Colorado State University in 1989, and a Masters Degree in Public Health (Epidemiology) from Tulane University in 1990. In addition to epidemiology he is trained in biostatistics, evaluation and operations research and is skilled in data base design and development. He specializes in developing simulation models and quantitative risk analyses for animal diseases and animal products.

Evaluation of U.S. System for Control and Eradication of Tuberculosis in Cattle

Introduction

USDA-APHIS published a final rule on October 23, 2000 that specifies state and zone designations and movement controls for tuberculosis in cattle, bison and captive cervids. This final rule refers to the Uniform Methods and Rules (UMR) of January 22, 1999. The Veterinary Service's Memorandum 552.15 of November 10, 1999 supplements and clarifies the UMR. These three documents define the current U.S. system of control and eradication of tuberculosis in cattle. This system is based on the judgment of experienced epidemiologists but is not supported by quantitative analysis.

The goal of this study is to determine the efficiency and effectiveness of the implementation of the current U.S. system as it applies to:

1. Current status of tuberculosis of cattle of the United States.
2. Countries or regions who wish to export cattle to the United States and who agree to the implementation of the current U.S. system of control and eradication of tuberculosis.

Model Description

Quantitative analysis, using a simulation model applied to a zone under various scenarios specified for 1 and 2 above, is the method chosen to determine the efficiency and effectiveness of the system. A zone is defined as an area of a country, region, or state. Each scenario of a zone is described by input to the simulation model that specifies:

1. Effectiveness of abattoir inspection and laboratory tests and effectiveness of herd identification of slaughtered animals confirmed as infected with tuberculosis (TB).
2. Effectiveness of trace procedures to identify to herds implicated as sources of infection as well as herds acquiring TB exposed animals.
3. Effectiveness of tests carried out during herd testing.
4. Number of herds contained in the zone.
5. For each herd of the zone, the type of herd and management practices, the number and type of animals, and the assumed prevalence of TB infection at the start of the simulation.

The model simulates the yearly activity of detection of TB and the status of herds. During the process, the simulation model keeps track of all the surveillance carried out in the zone and the status and activity of each herd and each animal in each herd.

For each year of the simulation, the model reports the following information for the zone:

1. Actual number of herds infected at the beginning and end of the year.
2. Total number of herds reported infected during the year.
3. Risk class determined for the zone at the beginning of the year.
4. Number of accredited herds at beginning of the year.
5. Number of herds depopulated or quarantined during the year.
6. Number of herds in quarantine status at the beginning of the year.
7. Number of animals moved within and outside zone during the year, total and infected, summarized by type of movement, type of herd, age and breeding status.
8. For each type of surveillance procedure, the number of herds detected as infected during the year.

Basic Characteristics of the Simulation

1. Each animal in each herd is "tracked" from the time that it "originates" in the model until the animal is slaughtered or sold to another herd outside of zone.
2. An animal "originates" either at the start of the simulation, when each herd is populated according to the input herd parameters, or when the model replaces an animal slaughtered or sold with an animal other than an existing animal purchased from within the zone. The source and age of replacements are based on input parameters.
3. The number of animals in each herd is kept unchanged for each year of the simulation.
4. The age and breeding status of each animal is randomly established at the start of the simulation as specified by herd input. The breeding status of animals remains unchanged for all years of the simulation. However, the age composition of the herd (age status of animals) may change from year to year based on the slaughter, sales, and replacement activity or lack thereof. If an animal remains in the zone, its age is increased by 1 year each year of the simulation.
5. The infection status of each animal is randomly established at the start of the simulation as specified by herd input. As the simulation progresses in time, non-infected animals may become infected due to the spread of disease within the herd or due to infection from exogenous source. Moreover, when an animal is replaced, the replacement animal may be infected or non-infected, based randomly on the source of replacement and the infection status of the source of replacement.
6. At the start of the simulation, the origin of each animal is established randomly, based on the input herd normal source of replacement proportions. As the simulation progresses in time, when an animal is replaced, the origin of each replacement animal is based randomly on the same input herd normal source of replacement proportions. A record of the origin of each animal is maintained and used for trace back surveillance procedures.
7. During each year of the simulation, based on the input herd proportions, animals are randomly chosen for movement out of the herd, either within the zone or outside of zone. Movement out of the herd consist of animals shipped directly from premise to slaughter, shipped from premise to market to slaughter, shipped from premise to feed lot to slaughter, or animals sold to another herd.
8. All procedures are carried out randomly based on triangular distribution defined by parameter values: minimum, most likely, and maximum.

9. The results of the following test are based on input control parameters of test sensitivity and specificity and the infection status of the animal:
    - ? Laboratory test as part of abattoir inspection procedure
    - ? Caudal fold test (CFT)
    - ? Comparative cervical test (CCT)
    - ? Cervical test (CT)
    - ? Post-mortem diagnosis and laboratory test

The CEAH Mission

CEAH produces timely, factual information and knowledge about animal health. With a view to the future, CEAH explores and analyzes animal health and related agricultural issues to facilitate informed decision-making in government and industry.

CEAH also partners with the Office International des Epizooties (OIE) and its member countries to improve international disease surveillance capabilities and analytic methods supporting trade decisions.

CEAH has a multidisciplinary staff that includes agriculture economists, spatial analysts, GIS and computer specialists, veterinary epidemiologists, technical writer/editors, and data managers.

We're on the Web!
www.aphis.usda.gov/vs/ceah/

In order to accomplish our mission we:

- ? Partner with our customers and colleagues to provide quality and timely products, services and support.
- ? Promote individual growth and encourage creativity.
- ? Continually research the benefits of new technology.
- ? Remain responsive to a changing global environment and its opportunities.
- ? Expand our customer base in animal health and actively seek new clients within the APHIS community.
- ? Support international trade and emergency responsiveness.
- ? Motivate our team.

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